Vibration Test Plan
To Characterize the TDC Stirling Engine
For Future Technology Development

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Test Objective:

Characterize the Stirling Engine's (55We Stirling convertor) performance when subject to dynamic loads produced by vibration testing. This test will be performed on developmental hardware to gain insight on fundamental issues. This test is not meant to be a qualification, an acceptance or a strength test. Follow-on testing of flight prototypical hardware (planned for late FY00) will seek to verify the hardware to its expected dynamic flight requirements.

Notes on Test Philosophy:

1. Testing to occur at NASA Glenn Research Center's (GRC) Structural Dynamics Laboratory (SDL). Test is scheduled for the week beginning on November 29, 1999.

2. The tall pole (from SDL's perspective) in making this schedule is the designing and manufacturing of the test fixture. In order to meet the deadline for fixture manufacturing, the fixture concept was finalized on November 8, 1999.

3. Engine will be operated during vibration testing.

4. Engine performance will be monitored during testing by Stirling Technology Company (STC) and GRC's Power & On Board Propulsion Technology Division personnel. Instrumentation will be used as a determination as to whether it is safe to proceed to the next highest test level.

5. Random vibration workmanship testing and a low-level sine vibration testing will be performed. The basis for the random vibration test levels is the workmanship levels from NASA-STD-7001, with a slight modification. The basis for the sine test levels is SDL's past practice. These test levels are chosen to characterize the structure and are not meant to represent the JPL dynamic requirements.

6. The random vibration workmanship test level will slowly be approached in 6 dB increments starting significantly below maximum test levels. The sine test levels will begin at 0.25 g, and be slowly incremented in steps of 0.125 g.

7. When and if these tests are successfully completed, additional random vibration testing up to the JPL D-15517 specified qualification levels may occur. These test levels will be approached in 3 dB increments, starting at 6 dB below the JPL qualification levels.

8. NASA GRC SDL will monitor both the control and response acceleration measurements. Acceleration limits on selected measurements may be utilized. For all sine testing, a limit of 50 g's will be utilized.

9. Engine will be tested in one axis at a time. Two axes will be tested. **The engine's lateral direction (in same direction as cooling tubes' length) will be tested first.**

<u>The engine's axial direction will be tested second.</u> Test will include Stirling engine functional tests.

10. Start at full stroke and change to dither as needed for all vibration testing.

11. Locations of Instrumentation (minimum set):
    - Accelerometers
        - end of alternator (triaxial accelerometer)
        - top of housing (two biaxial accelerometers)
        - input to housing (two biaxial accelerometers)
        - hot end (laser measurement if possible)
        - fixture (two control accelerometers, in direction of shake)
        - cooling tube support (two accelerometers to monitor motion of tubes)
    - Other
        - Force (axial only at fixture flange)
        - Microphone
        - Internal pressure measurement
        - Output voltage
        - Current
        - Temperature (~ 4 on the heater head and ~2 in the coolant)
        - Heater voltage and current
        - Cooling water flow

<u>Basic Test Plan:</u>

1. Assemble TDC for vibration test and document per established STC assembly procedures.

2. Perform pre-test inspection and full performance testing of the TDC <u>at STC</u>. Ship TDC test hardware to GRC.

3. Perform bare fixture checkout of all planned forcing excitations. Mount Stirling Engine test hardware upon completion of checkout of test setup and test excitations. Lateral axis should be tested first. Axial axis should be tested second.

4. Perform pre-test checkout, including alternator megaohm check followed by functional checkout at nominal 650°C T_{hot}, 30°C T_{cold}, and full stroke. Functional check to be at steady state conditions with T_{hot} and T_{cold} rate of change less than 1°C per 2 minute time period. Record all input and output parameters that are available.

5. Perform low-level sine test to characterize resonances below 2000 Hz. <u>Stop testing when/if engine conditioning instrumentation warrants.</u>

    - 0.25 g sine sweep (5-2000 Hz) at 4 octaves/minute
    - A limit of 50 g's will be utilized.

- Start at full stroke and change to dither as needed.

6. Perform post low-level sine test functional checkout with same Q_{in} as step 4 and at nominal 650°C T_{hot}, 30°C T_{cold}, and full stroke. Functional check to be at steady state conditions with T_{hot} and T_{cold} rate of change less than 1°C per 2 minute time period. Record all input and output parameters that are available.

7. Perform random vibration test up to recommended workmanship levels as given in table below (see table in Step 9). Start at 30 dB below full workmanship levels (approximately 0.21 grms overall) and slowly proceed to full levels (-30 dB, -24 dB, -18 dB, -12 dB, -6 dB, - 3 dB and 0 dB (full level)). Each 6 dB increment represents a doubling of grms. <u>Start at full stroke and stop testing as needed to change to dither stroke when/if engine condition instrumentation warrants</u>.

8. If contact or other significant event is indicated at full stroke, then perform functional checkout <u>before changing to dither stroke</u>. Use same Q_{in} as step 4 and nominal 650°C T_{hot}, 30°C T_{cold}, and full stroke. Functional check to be at steady state conditions with T_{hot} and T_{cold} rate of change less than 1°C per 2 minute time period. Record all input and output parameters that are available. Change to dither stroke and achieve steady operation at nominal 650°C T_{hot} and 30°C T_{cold}. Record dither stroke functional check data point.

9. Perform random vibration test at dither stroke up to recommended workmanship levels as given in Table below. Start at 30 dB below full workmanship levels (approximately 0.21 grms overall) and slowly proceed to full levels (-30 dB, -24 dB, -18 dB, -12 dB, -6 dB, - 3 dB and 0 dB (full level)). Each 6 dB increment represents a doubling of grms.

   Testing at levels below full level (6.8 grms) should be for 30 seconds/level/axis. <u>Stop testing when/if engine conditioning instrumentation warrants.</u>

   <u>Workmanship Random Vibration Test Levels</u>
   <u>(Slightly modified from NASA-STD-7001):</u>
   Test duration = 1 minute in each axis at full level

20 Hz	0.016 g^2/Hz
20-50 Hz	+3 dB/octave
50-500 Hz	0.04 g^2/Hz
500-2000 Hz	-3 dB/octave
2000 Hz	0.01 g^2/Hz
Overall	6.8 grms

   <u>Test Control Tolerance Levels for Random Vibration Test Levels</u>:
   Acceleration PSD (maximum filter bandwidth of 25 Hz) = +/- 3 dB
   Overall Grms = +/- 1 dB

10. Perform post random vibration test functional check first at dither stroke and then at full stroke with same Q_{in} as step 4 and at nominal 650°C T_{hot}, 30°C T_{cold}. Functional

check to be at steady state conditions with T_{hot} and T_{cold} rate of change less than 1°C per 2 minute time period. Record all input and output parameters that are available.

11. Perform low-level sine test to identify any resonance signature change due to random vibration testing (i.e. repeat step 5). <u>Stop testing when/if engine conditioning instrumentation warrants.</u>

    - 0.25 g sine sweep (5-2000 Hz) at 4 octaves/minute
    - A limit of 50 g's will be utilized.
    - Compare resonances from step 11 with those of step 5
    - Start at full stroke and change to dither as needed.

12. Perform post low-level vibration test functional checkout with same Q_{in} as step 4 and at nominal 650°C T_{hot}, 30°C T_{cold}, and full stroke. Functional check to be at steady state conditions with T_{hot} and T_{cold} rate of change less than 1°C per 2 minute time period. Record all input and output parameters that are available.

13. Perform additional low-level sine test to further characterize test hardware. <u>Stop testing when/if engine conditioning instrumentation warrants</u>.
    - Start at full stroke and change to dither as needed.
    - A limit of 50 g's will be utilized.
    - 0.25 g sine sweep (2000-5 Hz) at 4 octaves/minute (sweep down in frequency)
    - 0.375 g sine sweep (5-2000 Hz) at 4 octaves/minute
    - 0.50 g sine sweep (5-2000 Hz) at 4 octaves/minute
    - 0.50 g sine sweep (2000-5 Hz) at 4 octaves/minute (sweep down in frequency)

14. Perform post low-level sine test functional checkout with same Q_{in} as step 4 and at nominal 650°C T_{hot}, 30°C T_{cold}, and full stroke. Functional check to be at steady state conditions with T_{hot} and T_{cold} rate of change less than 1°C per 2 minute time period. Record all input and output parameters that are available. Shut down TDC and perform alternator megaohm check.

15. <u>**Repeat steps 3-14 for testing in second axis**</u>**.**

16. <u>Upon successful completion of workmanship random vibration and low-level sine testing **in both axes**</u>, perform higher level random vibration testing up to the Qualification levels stated in JPL D-15517. <u>**Lateral axis should be tested first. Axial axis should be tested second.**</u> Levels are referenced to JPL's D-15517 flight acceptance (FA) levels, shown in Table below (see step 17). Perform pre-test checkout, including alternator megaohm check followed by functional check at nominal 650°C T_{hot}, 30°C T_{cold}, and full stroke. Functional check to be at steady state conditions with T_{hot} and T_{cold} rate of change less than 1°C per 2 minute time period. Record all input and output parameters that are available. Start at full stroke and change to dither as needed.

17. <u>If contact or other significant event is indicated at full stroke, then perform functional checkout before changing to dither stroke</u>. Use same Q_{in} as step 16 and nominal

650°C T_{hot}, 30°C T_{cold}, and full stroke. Functional check to be at steady state conditions with T_{hot} and T_{cold} rate of change less than 1°C per 2 minute time period. Record all input and output parameters that are available. Change to dither stroke and achieve steady operation at nominal 650°C T_{hot} and 30°C T_{cold}. Record dither stroke functional check data point and continue random vibration test. Stop testing when/if engine conditioning instrumentation warrants.

Testing should be done as follows:

A) - 3 dB for 30 seconds/axis (FA - 3 dB, 6.2 grms)
B) 0 dB for 1 minute/axis (FA = Flight Acceptance, 8.7 grms, see table below)
C) +3 dB for 3 minutes/axis (FA + 3 dB = Qualification, 12.3 grms)
D) Perform post random vibration test functional check first at dither stroke and then at dither stroke with same Q_{in} as step 16 and at nominal 650°C T_{hot}, 30°C T_{cold}. Functional check to be at steady state conditions with T_{hot} and T_{cold} rate of change less than 1°C per 2 minute time period. Record all input and output parameters that are available.
E) Perform low-level sine test to identify any resonance signature change due to higher level random vibration testing.
   - Start at full stroke and change to dither as needed.
   - 0.25 g sine sweep (5-2000 Hz) at 4 octaves/minute
   - A limit of 50 g's will be utilized.
   - Compare resonances from step 17E with those of step 11.

FA Random Vibration Test Levels (from JPL D-15517):

Test duration = 1 minute in each axis

20 Hz	0.0064 g^2/Hz
20-50 Hz	+9 dB/octave
50-250 Hz	0.10 g^2/Hz
250-350 Hz	-6 dB/octave
350-1000 Hz	0.05 g^2/Hz
1000-2000 Hz	-12 dB/octave
2000 Hz	0.0031 g^2/Hz
Overall	8.7 grms

Tolerance Levels for Random Vibration Test Levels:
Acceleration PSD (maximum filter bandwidth of 25 Hz) = +/- 3 dB
Overall Grms = +/- 1 dB

18. Perform post high-level random test functional check at nominal 650°C T_{hot}, 30°C T_{cold}, and full stroke. Functional check to be at steady state conditions with T_{hot} and T_{cold} rate of change less than 1°C per 2 minute time period. Record all input and output parameters that are available. Shut down TDC and perform alternator megaohm check.

19. **Repeat step 16-18 for second axis.**

20. Upon completion of testing at GRC, ship to STC and perform post-test inspection and full performance testing at STC.

21. Disassemble TDC following vibration test and performance test and document per established STC disassembly procedures.

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